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The Quaternary Stratigraphy in the Northern Basin of the Central Plain, Thailand

by

Tomoo HATTORI*

TAKAYA proposed a Quaternary stratigraphy for the Central Plain of Thailand based on his observation of natural outcrops (TAKAYA, 1968). During field survey, he paid special attention to the relationship between the degree of weathering and stratigraphical position. To examine the relationship in more detail, the author made a field survey and sample collection with the help of TAKAYA during the period from November, 1968 to January, 1969. In this report, the result of the field survey and subsequent laboratory work is presented. A proposal concerning a new formation is also made which modifies TAKAYA's stratigraphy.

I The Geomorphological Setting of the Sampling Sites

The surveyed area coincides with the northern half of the Central Plain of Thailand, called "The Northern Basin of the Central Plain of Thailand", by TAKAYA. A simplified physiographical map of the area, drawn by TAKAYA after the joint survey with the author, is shown in Fig. 1. In the map, gentle relief, low lying, Quaternary land is divided into two parts, alluvial valley, and marginal area. The geomorphological implication is that the former is the area in which depositional agents currently dominate, while the latter is dominantly erosional. Beside the geomorphological division, the area is roughly divided into four provinces, Si Sachanarai-Uttradit, Sukhothai-Phitsanulok, Taphan Hin-Kao Sai, and Nakhon Sawan-Kampheng Phet, for convenience of arranging the sampling localities. The sampling localities are shown in the physiographical map of Fig. 1, and their geomorphological as well as provincial setting are tabulated in Table 1.

The descriptions of profiles from which samples were collected are given in Appendix where the field occurrence and the selected mineralogical properties are tabulated horizontally. The geomorphological outline of the sampling sites may be quickly obtained from the sketches shown in Fig. 2 to 4. Figs. 2 and 3 are sketches of typical outcrops of the Si Sachanarai and Taphan Hin provinces, respectively. In the pictures, several different formations or sediments of different ages, are illustrated

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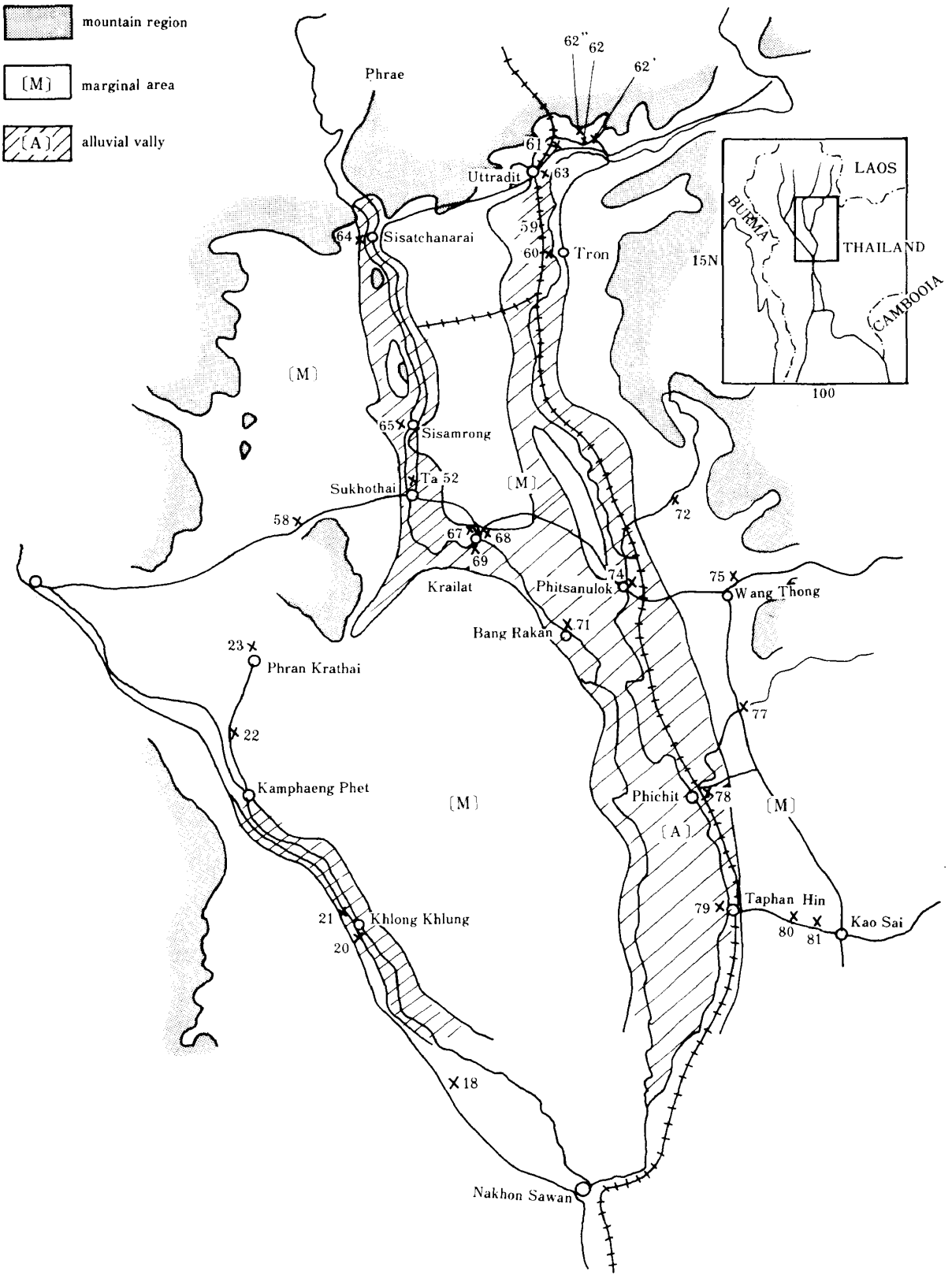
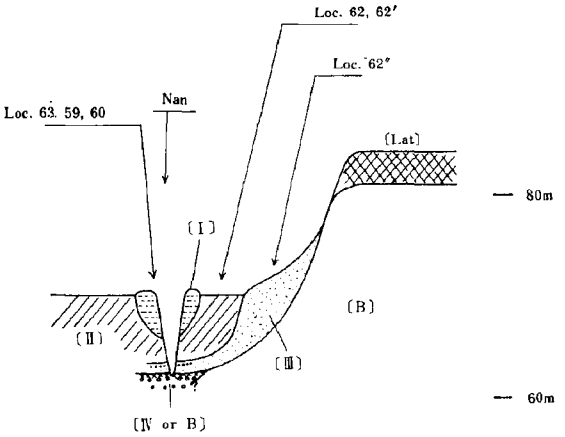


Fig. 1 Northern Basin and locality of sampling outcrops (drawn by Y. TAKAYA)

Table 1 Geomorphological division of surveyed outcrops with respect to the provinces

	Alluvial valley	Marginal area	
		along the river	terraces or foot of hill
Si Sachanarai–Uttradit	No. 67,68,69,71,74,78	No. 59,60,63,64	No. 62,62′,62″
Sukhothai–Phitsanulok		No. 65, Ta52*,72,77	No. 58,75
Taphan Hin–Kao Sai		No. 79	No. 80,81
Nakhon Sawan–Kampheng Phet		No. 20	No. 18,21,22,23

* This outcrop was surveyed by TAKAYA at his first survey. Description has been presented in his report (TAKAYA, 1968) and mineralogical characteristic has been reported by HATTORI (HATTORI, 1969).



〔I〕 : Formation I
〔II〕 : Formation II
〔III〕 : Formation III
〔IVorB〕 : Formation IV or Basement
〔Lat〕 : Hard Laterite Crust

Note : On this picture, if the *Nan* is replaced by the Yom, Loc. 64 can be placed exactly the same position as what occupied by Loc. 63.

Fig. 2 Schematic cross section arround Uttradit and geomorphological and stratigraphical setting of sampling sites

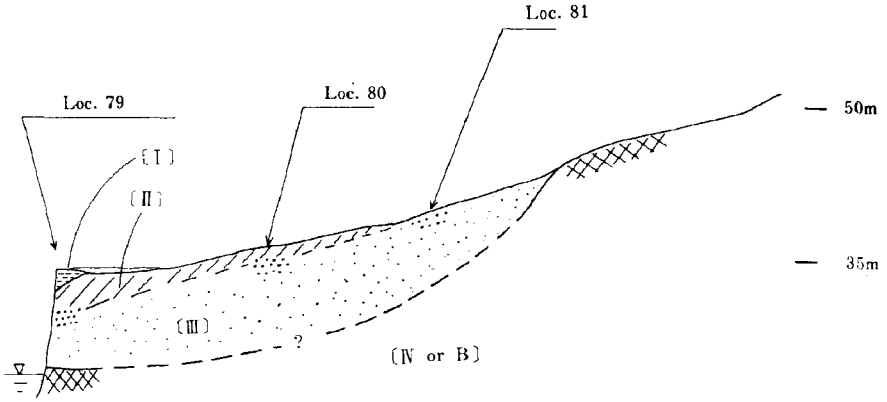


Fig. 3 Schematic cross section between Taphan Hin and Kao Sai and geomorphological and stratigraphical setting of sampling sites

so as to show their stratigraphical relationship. Outcrops of the Nakhon Sawan province are in most cases quite similar to those of the Si Sachanarai province.

The terminologies, For. I to IV, which appeared on Figs. 2 and 3, were originally defined by TAKAYA (TAKAYA, 1968). Each formation has its own range of weathering degree. Considering the normal outcrops, For. II contains pisolitic iron-manganese concretions in its upper part, For. III has a thin (3 to 10 cm.) lateritic cap and For. IV a thickly (more than 5 m.) laterized upper portion.

Fig. 4 shows two topographical cross sections, one passing ca. 10 km. north of Sukhothai or parallel to 17° 05′ N latitude and the other passing ca. 10 km. south of Phitsanulok or parallel to 16° 45′ N latitude. On the cross section, the relative topographical relationship between the alluvial valley and the marginal area is shown clearly. The alluvial valley lies lower than the surrounding marginal area. The geologically interesting thing, though not illustrated in the figure, is that the accumulation of formations, like those shown in Figs. 2 and 3, is not seen in the alluvial valley. This particular topic will be discussed later in this paper.

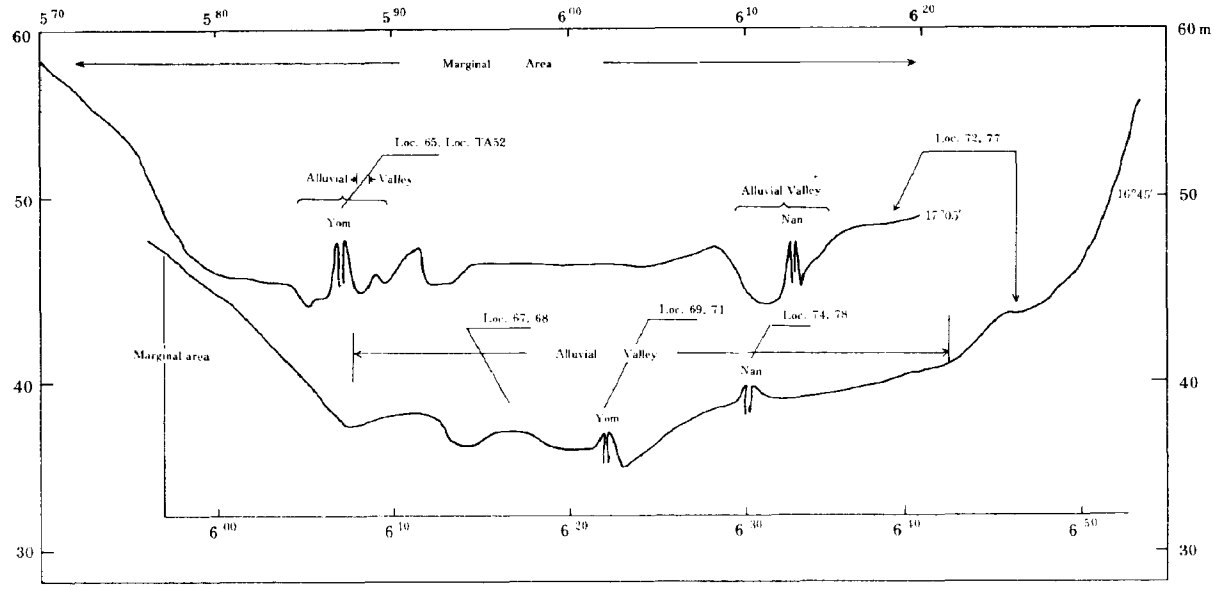


Fig. 4 Cross sections at 17°05′ (ca. 10 km N of Sukhothai) and 16°45′ (ca. 10 km S of Pitsanlok) and geomorphological settings of surveyed outcrops

II The Weathering Degrees of Substrata

The weathering degrees of the samples are listed in Appendix using selected indices. The method of experiment was stated in a previous paper by the author (HATTORI, 1970). The indices of weathering degree adopted here are the silt-clay ratio, the kaolin mineral content in clay fraction, the width of d_{001} peak of kaolin mineral and intensity ratio of 14 to 10 Å peak in the X-ray diffraction diagram of the calcium air-dried

oriented specimen, and the relative abundance of feldspars in the fine sand fraction throughout an outcrop. As mentioned in the previous paper, the author thinks that the above indices may change with progress of weathering as follows: (1) the silt-clay ratio decreases, (2) the kaolin mineral content increases, (3) the width becomes wider, (4) the intensity ratio also becomes greater, (5) the feldspars in the fine sand fraction disappear. Such interpretations, however, may be applied with more difficulty when the sources of sediment are diverse.

To examine the general trend of the changing pattern of weathering degrees in a formation, some of the results have been recorded in Table 2. The table demonstrates that every property is quite diagnostic when it is used for comparison of the weathering degree of samples belonging to the same formation in an outcrop. When different samples belong to the same formation in the same outcrop, the ones taken from shallower depth tend to be more weathered. The indices do not seem to be as powerfully diagnostic as when the subjects belonging to different localities are compared. But even in this situation, kaolin mineral contents, if not true for other properties, serve as an adequate indicator. The results obtained from mineralogical studies may be generalized into a schematic picture as shown in Fig. 5. The picture demonstrates that the direction of weathering always tends to form more kaolin minerals and iron oxides in the uppermost part of each formation. Thus when ideal profile, in which no truncation took place during the depositional breaks, is given, orderly cycles are seen in the contents of kaolin minerals and iron oxides. The kaolin minerals and iron oxides have their maximum contents just beneath disconformity surfaces, and decrease rapidly downward until they level off at a depth of some one meter below the surfaces. This cyclic changing pattern of weathering degree deduced from the laboratory work seems to agree with the weathering pattern observed by the naked eyes in the field.

Table 2 Some properties of selected samples belonging to the same formation

Sample number	Clay % in fine soil	Silt/clay	Kaolin % in clay fraction	Width of d_{001} peak of Kaolin degree	Peak intensity ratio at 14Å and 10Å	Feldspar in sand fraction	Free iron oxides %
64–8	40.1	0.61	50	1.00	0.67	±	3.40
9	39.9	0.73	45	0.87	0.80	+	2.70
10	38.1	0.45	30	0.83	2.50	++	1.93
18–1	56.1	0.23	75	1.02	0.25	+	4.40
2	54.6	0.18	70	1.00	0.50	+	1.59
3	40.4	0.17	65	0.88	0.40	++	2.07
4	19.3	0.32	60	0.71	0.33	+++	1.00
63–5	44.3	0.86	45	0.81	0.83	−	4.64
	44.8	0.74	40	0.81	1.00	−	4.54

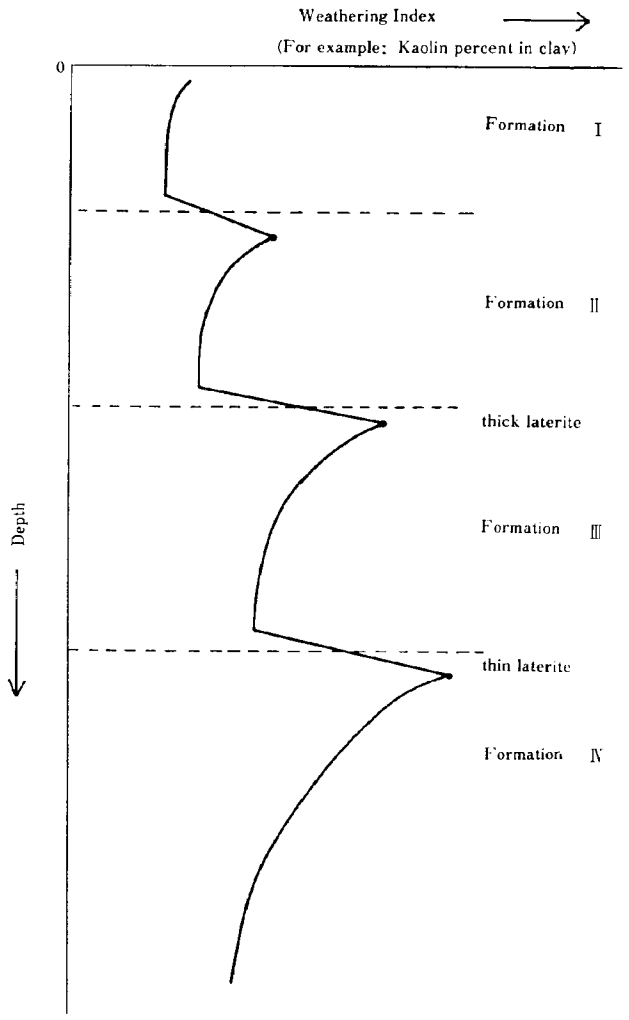


Fig. 5 Schematic change of weathering index throughout profiles

A fact to be added here is that there are differences in the clay mineralogy of deposits between the northern and southern parts of the marginal area. The most distinct difference is that the southern part almost completely lacks illite minerals, whereas the north usually has a balanced mineral composition with considerable amount of illite, kaolin and 2 : 1 type minerals. The fact that deposits in the south are commonly associated with considerable amount of feldspar grains in sand fraction is also a distinct characteristic. These facts may be explained by the fact that the sediments on the marginal area seems to reflect the character of the geological bodies on or very close to which the sediments rest. The boundary separating the two parts seems to be drawn by linking Khlong Khlung on the Ping River with Taphan Hin on the Nan River.

III Proposal of Formation I'—A Revised E–W Cross Section

The author's laboratory work confirmed the validity of TAKAYA's supposition on the high correlation between the weathering degree and stratigraphical position. But at the same time the author came to a conclusion that some modification in this supposition, nevertheless, needs to be made. The main difference throughout the entire Northern Basin, while the author thinks that it is applicable only in the marginal area. The author's proposed revision is based on the following facts:

A sharp contrast exists between the outcrops in the alluvial valley and those in the marginal area. Outcrops in the marginal area, as mentioned before, almost exclusively provide accumulation of strata of different weathering degree, such as the non-weathered first layer, the pisolitic iron concretion-bearing second layer, thin

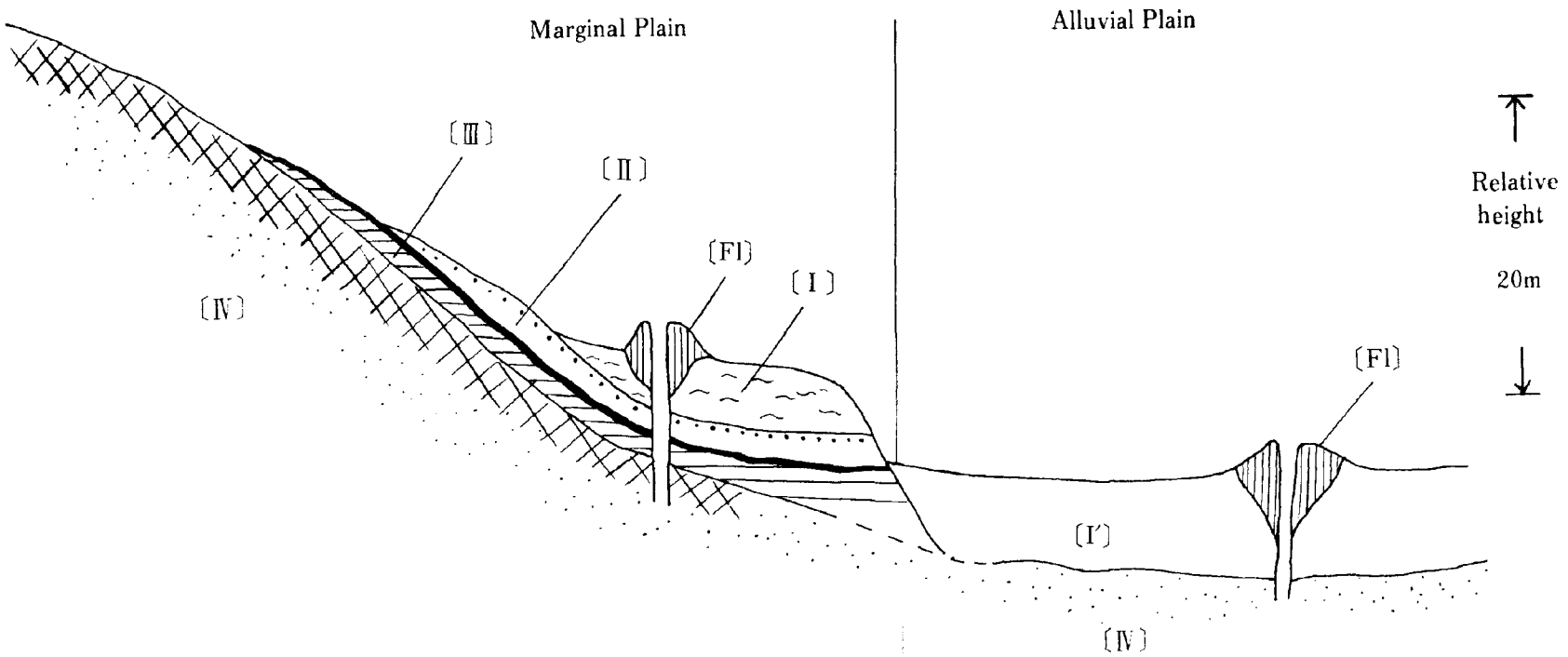
lateritic capped third layer, and an occasional, thick laterite-covered forth layer, in descending order. In the alluvial valley, by contrast, this type of accumulation is not seen; only two layers are found here, i. e. a loose, upper layer, and a red plinthitic mottle-bearing and slightly indulated lower layer. Though the upper layer sometimes contains iron nodules, typical iron concretions do not appear. The layer does not show any distinct features of weathering. The point to which attention should be paid here is in this upper layer. TAKAYA thought that the iron nodules which are occasionally interbedded in the layer were evolved in situ. Thus he identified the upper layer containing the nodules as For. II, the rest being For. I.

The author observed the same outcrops in a different way. He supposes that the nodules have been transported rather than evolved in situ. The field occurrence of the nodules is reminiscent of another example of gravelly iron nodule bearing sediments in the Lampang Basin (HATTORI, 1970). Laboratory data also supports the author's interpretation. The kaolin mineral content of the horizon is 30 to 40 per cent and most mineralogical properties correspond to those of For. I in the marginal area regardless of the presence of the nodules. These facts suggest that all the upper layer be correlated to For. I.

The author's idea is schematically illustrated in Fig. 6, using an E-W cross section of the area. A new formation For. I′, is introduced here. This is applied to the upper layer in the alluvial valley in question. The reason why the author proposes new formation is that inspite of the mineralogical similarity, there exist a few notable differences in characteristics between the two formation, such as a conspicuous elevational gap, different thickness, and the different successional pattern. If the terminology For. I is applied to the deposits of both areas equally, it may cause confusion, or at least it is very difficult to show the contrast distinctly. The correlation between the two ideas is as follows:

TAKAYA (1968)	The author	
	Marginal area	Alluvial valley
Formation I	Formation I	Formation I′
Formation II	Formation II	lack ?
Formation III	Formation III	lack ?
Formation IV	Formation IV	Formation IV

The difference between the two ideas seems to be attributed to the fact that TAKAYA thought of the survey area as being essentially erosional, whereas the author believes that at least the valley zone is depositional in character.



For IV	For III	For II	For I	For I′	For IV
Gently sloping but undulating surface				Flat but slightly undulating surface	
Heavily weathered alluvium covered by thich laterite	Heavily weathered alluvium covered by thin laterite	Weathered alluvium with pisolitic concretion	slightly weathered alluvium with fine iron concretion	slightly weathered alluvium with fine iron concretion and sometimes carried pisolitic concretion	slightly or heavily weathered alluvium with plinthic mottles

Fig. 6 Tentative stratigraphy in the northern basin

Acknowledgement

This report is a part of the field survey and laboratory study of Quaternary pedology conducted by the Center for Southeast Asian Studies of Kyoto University from November, 1968 to January, 1969.

The author is deeply indebted to the National Research Council of the Thai Government and the Department of Geology of Chulalongkorn University for their approval of, and the assistance in this research in Thailand. Thanks is also due to Dr. TAKAYA who assisted the author during the field survey and gave him helpful advice.

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Appendix 1 Brief description of outcrops and some properties of substrata covered on Lateritic layer

Depth (cm)	Sample No.	Description	Formation	pH	Clay %	Silt/Clay	Kaolin %	Width of d_{001} peak Kaolin degree	Peak Intensity Ratio 14Å/10Å	Feldspar in Fine Sand
	Loc. 72	Ca. 1 km east of Wang Thong								
40	72–1	very pale brown (10YR8/4)(dry) loamy sand	?	5.1	7.3	0.55	60	0.82	1.07	–
100	–2	yellow (10Y7/8) and very pale brown (10YR8/4) (dry) loamy sand	?	4.7	10.1	0.43	65	0.82	1.33	–
140	–3	gray sandy loam, common yellowish brown cloudy mottles	?	4.5	28.6	0.16	70	1.00	2.00	–
		nodular lateritic layer								
		unweathered hard rock (Sandstone)	Basement							
	Loc. 22	Ca. 3 km north of Kampheng Phet								
10	22–1	white (10YR8/2) (dry) clay loam	?	4.7	25.4	0.92	35	0.62	0.18	–
		hard laterite								
	Loc. 58	Ban Dan								
10	58–1	very pale brown (10YR8/4) (dry) sandy loam	?	5.7	10.8	1.70	40	0.80	3.00	–
50	–2	nodular laterite	?	5.4	16.8	0.79	40	0.80	5.00	–
		hard honeycomb structured laterite with quartzite								

Appendix 2 Brief description of outcrops and some properties of substrata in Si Sachanarai–Uttradit Area

Depth (cm)	Sample No.	Description	Formation	pH	Clay %	Silt/Clay	Kaolin %	Width of d_{001} peak Kaolin degree	Peak Intensity Ratio 14Å/10Å	Feldspar in Fine Sand
	Loc. 59	Right bank of the Nam, Ca. 5 km north of Tron Station								
x	59–1	pink (5YR7/5)(dry) light clay, very few fine manganese concretion	I	7.3	31.7	1.03	40	0.89*	0.71	+
x+200	–2	light reddish brown (2.5YR6/4)(dry) light clay, few fine manganese concretion	I	7.5	33.7	1.18	35	0.79*	1.02	
x+210	–3	pale reddish orange (2.5YR7/4)(dry) light clay, few yellowish brown cloudy mottles, few, fine manganese concretions	I	7.7	32.6	1.20	35	0.84*	0.87	
x+320	–4	white (10YR8/2)(dry) heavy clay, few to common yellow small cloudy mottles	I	7.6	50.6	0.74	40	0.82*	0.57	
x+360		hard honey comb structured laterite	IV							
	–5	white (N8)(moist) heavy clay, many reddish yellow and red large mottles	IV	7.4	47.0	0.24	70	0.74	2.00	–
	Loc. 60	Right bank of the Nan, Tron Station								
600	60–1	light reddish brown (5YR6/4)(dry) clay loam	I	6.2	25.1	0.74	30	0.74	0.75	##
610	–2	light reddish brown (5YR7/4) (dry)light clay, few to common reddish yellow medium cloudy mottles, common pisolitic iron concretions	II	6.8	29.5	0.48	40	1.00	1.00	
660	–3	white (10YR8/2)(dry) light clay; many reddish yellow medium cloudy	II	7.0	41.0	0.60	45	1.00	0.71	
680	–4	reddish yellow (7.5YR6/8) and pinkish white reticularly mottled heavy clay, many pisolitic concretions	II I	7.5	50.6	0.42	50	1.00	1.00	±
880		hard honeycomb structured laterite								

	Loc. 62	Ca. 13 km northeast of Uttradit								
40	62-1	pinkish gray (7.5YR6/2)(dry) light clay	II	5.7	42.0	1.07	40	0.67	0.71	
	-2	pinkish gray(7.5YR7/2)(dry) heavy clay, common reddish yellow concentrations	II	6.1	59.6	0.59	40	0.81	0.71	
	Loc. 62′	near Loc. 62								
10		gray brown light clay								
	62′-1	white (10YR8/2)(dry) light clay, common pinkish gray concentrations	II	6.2	37.8	0.98	45	0.76	0.57	
40	-2	yellowish red (5YR4/8)(dry) heavy clay, common manganese spots	II	6.5	56.5	0.61	40	0.82	0.50	
	Loc. 62″	Ca. 0.5 km north of Loc. 62								
30		grayish brown light clay	II or III	5.0	36.4	1.08	50	0.64	0.25	±
	Loc. 63	Right bank of the Nan, Uttradit								
	63-1	white (2.5Y8/2)(dry) light clay, few yellow fibrous mottles, very few very fine pisolitic concretions	I or Fl	5.6	38.8	1.10	45	0.77	0.83	
20	-2	light reddish brown (5YR6/4) heavy clay, common reddish yellow cloudy mottles, few manganese spots	I	6.0	52.8	0.73	45	0.77	0.83	
	-3	pink (5YR7/4)(dry) light clay, yellowish red cloudy mottles, few manganese spots and very fine concretions	I	6.0	37.3	1.07	40	0.80	1.00	
	-4	pink (7.5YR7/4)(dry) heavy clay, reddish yellow cloudy mottles, very few manganese spots	I	6.4	48.0	0.90	40	0.86	1.00	
120										

	-5	very dark brown (7.5YR2/2)(dry) heavy clay, common yellow and reddish brown cloudy mottles, common medium iron nodules	II	6.1	44.3	1.03	45	0.81	0.83	
	-6	pinkish gray (5YR7/2)(dry) heavy clay, common reddish yellow cloudy mottles, common medium iron nodules	II	6.0	44.8	0.86	40	0.81	1.00	
250										
	-7	weak red (2.5YR5.5/2) and white(10YR8/2) (dry) indurated heavy clay, many reddish yellow mottles	II	6.2	44.6	0.74	55	0.74	0.80	++
270										
	-8	weak red (2.5YR5/2)(dry) heavy clay, many reddish yellow mottles	III	6.0	47.3	0.66	45	0.78	0.83	
310										
	-9	yellowish brown (10YR5/8), brownish yellow (10YR6/8), brown (7.5YR5/4) and white indurated heavy clay	III	8.0	45.1	0.84	55	0.80	0.80	
460										
		hard laterite containing gravels	IV							
510										
	-10	white, red (10R5/8), reddish brown (5YR4/4) reddish yellow (7.5YR6/8)(moist) indurated sandy clay	IV	7.6	27.6	0.41	65	0.74	1.67	+
	Loc. 64	Left bank of the Yom, Si Sachanarai								
	64-1	very pale brown (10YR7/4)(dry) light clay, common reddish brown spots and concentrations	I	8.7	27.3	1.26	35	0.84	0.87	##
	2	white (10YR8/2)(dry) heavy clay, yellow cloudy mottles, few manganese spots	I	7.4	28.1	1.36	40	0.70	0.71	##
400										
	-3	white calcareous light clay massive	II	9.1	34.0	1.15	45	0.84	0.57	++
450										
	-4	pinkish white heavy clay, common reddish yellow cloudy mottles	II	8.4	51.6	0.70	45	0.94	0.57	
520										
	-5	white (10YR8/2)(dry) sandy loam, many yellow cloudy mottles		8.5	21.1	1.11	30	1.05	1.00	
620										
	-6	white (10YR8/2)(dry) light clay, many yellow and reddish yellow cloudy mottles, common manganese spots, many iron concretions	III	8.6	36.0	0.83	40	1.05	0.71	±
630										
	-7	white (10YR8/2)(dry) light clay many yellow and reddish yellow cloudy mottles, many manganese spots	III	8.6	30.1	0.64	40	0.96	0.57	±
690										

	-8	laterite cap	IV	8.7	40.1	0.61	50	1.00	0.67	±
740										
	-9	white (10YR8/2), light yellowish brown (10YR6/4), reddish yellow (7.5YR8/8) indurated light clay	IV	8.5	39.9	0.73	45	0.87	0.83	+
800										
	-10	weathered gravel layer	IV	6.8	38.1	0.45	30	0.83	2.50	++

* by Fe-Kα radiation

Appendix 3 Brief description of outcrops and some properties of substrata in Sukhothai-Phitsanulok Area

Depth (cm)	Sample No.	Description	Formation	pH	Clay %	Silt/Clay	Kaolin %	Width of d_{001} peak Kaolin degree	Peak Intensity Ratio 14Å/10Å	Feldspar in Fine Sand
	Loc. 65	Left bank of the Yom, Si Samrong								
			Fl or I							
x										
	65-1	brown (7.5YR5/4)(dry) sandy loam, few reddish yellow cloudy mottles thinly laminated	I	6.2	16.9	1.02	30	0.82*	0.75	++
x+100										
	-2	pinkish gray (7.5YR7/2)(dry) heavy clay, common reddish yellow fibrous and cloudy mottles, many plant remains	I	6.3	49.5	0.94	35	0.76*	0.44	
x+150										
	-3	white (10YR8/2)(dry) light clay, common reddish yellow spots, small pipe and fibrous mottles, very few iron nodules	II	5.8	32.5	1.43	40	0.72*	0.33	+
x+170										
	-4	white (10YR8/2)(dry) light clay, common fine iron concretions, few manganese spots	II	5.6	36.1	1.43	45	0.71*	0.38	+
x+180										
	-5	pinkish white (dry) heavy clay, many reddish yellow concentric mottles, common yellow cloudy mottles, few manganese spots	II or III	4.6	49.1	0.73	45	0.88*	0.38	±
x+300										
	-6	gravel layer with white clay staining by iron oxides	IV	5.3	44.4	0.08	40	0.98*	0.33	+
	-7	brown (7.5YR5/4)(dry) heavy clay, many manganese spots, few strong brown cloudy mottles	IV	6.5	43.7	1.03	35	0.79*	0.50	

	Loc. Ta 52	Left bank of the Yom, Sukhothai								
	Ta 52–1	yellowish brown massive loam	I				35		0.86	
	–2	brown clay with common plant remains	I				35		0.86	
260										
	–3	olive gray clay with common brown mottling	II				45		1.20	
330										
	–4	gray brown clay with common strong brown mottles and many iron concretions	III				60		1.67	
	Loc. 67	Ca. 13 km east of Sukhothai								
	67–1	light gray (2.5Y7/2)(dry) clay loam		5.4	34.9	1.45	35	0.61	0.57	+
20										
	–2	white (10YR8/2)(dry) clay loam, profuse iron concretions, yellow cloudy mottles, few manganese spots		5.5	26.7	1.25	40	0.74	0.71	+
35										
	–3	white (10YR8/2) and pinkish gray (7.5YR6/2) (dry) mozaic sandy clay loam, few brownish yellow cloudy mottles		6.2	18.7	0.76	35	0.80	0.57	++
	Loc. 68	Ca. 0.5 km southwest of the diversing point to Krailat								
	68–1	white (10YR8/2)(dry) clay loam, common yellowish brown cloudy mottles		5.2	31.7	1.99	40	0.72	0.71	++
10										
	–2	aggregation of pisolitic and botryoidal iron concretions with light clay		5.9	30.4	1.03	40	0.64	0.50	+
30										
	–3	pinkish gray (7.5YR7/2)(dry) light clay, few reddish yellow cloudy mottles common iron nodules		5.2	29.1	0.73	35	0.71	0.57	+
	Loc. 69	Left bank of the Yom, Krailat								
		sandy loam	Fl or I?							
100										

		purple clay								
	69–1	grayish brown (10YR5/2)(dry) heavy clay, many dark brown spots and concentration		5.1	74.8	0.26	40	0.72*	0.57	##
220										
	–2	reddish yellow (7.5YR6/6), dark brown (7.5YR4/4) and brown (7.5YR5/2) indurated heavy clay very few manganese spots and fine iron nodules		6.8	76.5	0.24	40	0.80*	0.50	
370										
	–3	light brownish gray (2.5Y6/2)(dry) heavy clay, few yellowish red cloudy mottles, few manganese spots		7.2	73.5	0.27	55	0.97*	1.25	–
520										
	–4	gray heavy clay, many dark red cloudy mottles, very few manganese and iron nodules	IV	6.6	57.1	0.54	40	1.30*	2.67	–
	Loc. 71	Right bank of the Yom, Bang Rakan								
		purple clay								
100										
	71–1	very pale brown (10YR7/4)(dry) heavy clay, very few yellow spots and concentrations, very few fine iron concretions		6.5	72.6	0.34	45	0.88*	0.57	
	–2	white (10YR8/2)(dry) light clay, many reddish yellow and yellow cloudy mottles		6.1	31.6	0.42	45	0.76*	0.57	##
	–3	white (10YR8/2)(dry) heavy clay, many yellow and yellowish brown cloudy mottles, common manganese spots and lime nodules		7.6	67.3	0.28	50	1.00*	1.50	–
300										
	–4	profuse iron concretions and nodules with clay		8.7	42.5	0.67	55	0.99*	1.25	–
320										
	–5	white (N8) heavy clay, common red spots and concentrations	IV	7.8	46.9	0.52	50	1.03*	0.67	–
370										
	–6	red (2.5YR5/8) and reddish yellow (5YR6/8) mozaic light clay, joints filling with white clayey materials	IV	8.2	41.4	0.43	50	1.20*	0.67	–
500										
	–7	reddish yellow (7.5YR6/6) light clay, joints filling with white clayey materials	IV	7.4	26.8	0.77	40	1.15*	1.00	+
	Loc. 74	Left bank of the Nan, Phitsanulok								

350	74–1	pinkish gray (5YR6/2)(dry) light clay, common reddish yellow spots and concentrations	I	5.9	34.0	1.15	35	0.89	0.86	±
	–2	pinkish gray (5YR7/2)(dry) clay loam, common reddish yellow cloudy mottles, many iron concretions and nodules	I	5.9	22.8	0.77	35	0.91	0.86	+
550	–3	light reddish brown (2.5YR6/4)(dry) heavy clay, common reddish yellow cloudy mottles	I	6.5	42.0	1.12	30	0.74	1.33	
580	–4	gray heavy clay, few yellow and reddish yellow cloudy mottles	I	6.5	71.3	0.35	35	0.50	2.25	+
690	–5	light brownish gray (2.5Y6/2)(dry) heavy clay, profuse reddish yellow cloudy mottles	I	6.5	50.1	1.19	35	0.70	1.17	
710	–6	gray heavy clay, few reddish yellow spots and concentrations	I	6.3	56.7	0.29	30	0.83	2.50	–
740	–7	gray and brownish yellow (10YR6/6) (moist) indurated loam	II	6.5	27.7	0.38	40	0.98	5.00	–
770	–8	white sandy loam, very few red mottles	II	6.8	15.8	0.59	45	0.70	4.50	–
810	–9	clay loam, look like plinthite	IV	6.7	25.6	0.43	50	0.62	4.00	±
870	–10	clay loam, many red mottles	IV	7.1	28.3	0.46	45	0.69	1.75	±
	–11	clay loam, many red mottles	IV	7.0	26.1	0.49	40	0.60	2.00	–
	Loc. 78	Right bank of the Nan, Phichit								
		Fresh sediment	F1							
x	78–1	reddish gray (2.5YR7/2)(dry) silty clay, few reddish yellow fibrous, tubular, filmy mottles	I	6.3	34.0	1.63	35	0.79	0.87	
x+50	–2	gray (N6)(dry) heavy clay, few reddish yellow pipe, spots, fibrous mottles		6.5	50.7	0.54	45	0.75	1.20	+
x+80										

	-3	grayish white (N7)(dry) heavy clay, common reddish yellow fibrous and filmy mottles		6.5	48.0	0.35	45	0.78	1.75	+
x+110	-4	gray (N6)(dry) light clay, many reddish yellow cloudy mottles		6.0	33.8	0.54	45	0.77	0.81	+
	-5	as same as above but mottles decrease		5.7	38.4	0.36	45	0.84	1.20	+
	-6	as same as above but mottles become large		5.9	35.1	0.42	40	0.80	1.00	+
	-7	as same as above but yellow mottles increase		6.4	28.1	0.67	40	0.89	1.00	+
	-8	white (10YR8/2)(dry) light clay, many yellow cloudy and red cloudy mottles		5.9	33.6	0.52	45	0.61	0.57	+
x+310	-9	reddish gray (2.5YR7/2)(dry) clay loam, mottles as same as above	B(IV)	5.1	20.3	0.78	40	0.78	0.72	+
	-10	pinkish white (5YR8/2) light clay, many reddish yellow and yellowish red spots and fibrous mottles	B(IV)	6.2	29.7	0.82	45	0.78	0.81	+
x+660										
	Loc. 72	Wat Pot								
	72-1	pinkish white (2.5YR7/2)(dry) sandy loam	I	6.6	11.0	1.58	40	0.54	0.72	±
150	-2	pinkish white (7.5YR8/2)(dry) light clay profuse weak red and reddish brown filmy mottles	II	4.0	35.6	0.97	40	0.57	1.40	−
350	-3	accumulation layer of iron concretions	II	4.2	31.6	0.45	45	0.80	2.67	−
390	-4	white light clay, few red mottles	IV	4.3	34.7	0.48	50	1.09	4.00	−
	-5	white light clay, few red mottles	IV	4.6	28.5	0.10	50	0.98*	1.00	−
	-6	light clay, many red mottles	IV	5.6	37.0	0.85	60	0.76*	1.67	−

	–7	heavy clay, common red mottles	IV	4.7	49.9	0.30	40	0.80*	1.40	–
	Loc. 77	Wattayom								
200										
	77–1	weak red (2.5YR5/2)(dry) light clay, common yellow cloudy mottles with manganese spots, many iron concretions and nodules	II	5.9	43.9	0.45	55	0.64	∞	–
230										
	–2	gray (N6)(dry) light clay, few dark brown cloudy mottles	III	6.4	40.1	0.53	65	0.33	∞	–
270										
	–3	same as above, common red mottles, gray clay balls	IV	5.0	39.9	0.44	70	0.32	5.00	–
370										
	–4	brown (7.5YR5/2)(dry) light clay	IV	3.0	39.9	0.55	65	0.33	5.00	–

* by Fe-Kα radiation

Appendix 4 Brief description of outcrops and some properties of substrata in Taphan Hin–Kao Sai Area

Depth (cm)	Sample No.	Description	Formation	pH	Clay %	Silt/Clay	Kaolin %	Width of d_{001} peak Kaolin degree	Peak Intensity Ratio 14Å/10Å	Feldspar in Fine Sand
	Loc. 79	Left bank of the Nan, Taphan Hin								
		brownish gray loam	I							
180										
		purple clay	I							
220										
		blueish clay	I							
240										
	79–1	pinkish gray (7.5YR6/2)(dry) heavy clay, few red spots and concentration	II	5.3	52.8	0.26	85	1.20	∞	–
410										

440	-2	pinkish gray (7.5YR6/2)(dry) light clay, common red and reddish yellow spots and concentration	II	5.3	43.2	0.28	75	1.04	∞	+
460	-3	white (N8)(dry) light clay, common strong brown and yellow cloudy mottles profuse iron concretions	III	5.3	30.4	0.33	75	1.01	∞	+
510	-4	white heavy clay, many red and brownish yellow concretionary mott es, few manganese spots		5.0	61.9	0.29	75	1.02	4.00	+
515		seam of carried iron concretions	III							
575	-5	white heavy clay, few reddish yellow cloudy mottles and few soft yellow concretions		5.2	57.1	0.31	75	1.00	∞	−
585	-6	light gray (10YR7/2), reddish gray (2.5YR7/2) reddish yellow (7.5YR7/6) indurated heavy clay	IV	7.5	41.3	0.61	60	1.04	1.00	
		white heavy clay, common red and reddish yellow mottles	IV							
	Loc. 81	Ca. 8 km east of Taphan Hin								
20	81-1	white (10YR8/2)(dry) light clay common yellow cloudy and fibrous mottles	III	6.2	29.6	1.27	75	0.91	∞	+
	-2	light gray (10YR7/2)(dry) light clay, common reddish yellow fibrous mottles	III	5.0	26.4	0.36	80	1.02	∞	+
	Loc. 82	Ca. 18 km east of Taphan Hin								
10	82-1	accumulation layer of iron concretions	III	4.5	21.1	1.80	75	1.02	∞	+
20	-2	light brownish gray(10YR6/2)(dry) light clay, few soft concretion and few red cloudy mottles	III	5.1	34.4	0.34	80	1.02	∞	+
	-3	light brownish gray (10YR6/2)(dry) light clay, few red spots and concentration	III	4.4	49.3	0.23	80	1.04	∞	−

Appendix 5 Brief description of outcrops and some properties of substrata in Nakhon Sawan–Kampheng Phet Area

Depth (cm)	Sample No.	Description	Formation	pH	Clay %	Silt/Clay	Kaolin %	Width of d_{001} peak Kaolin degree	Peak Intensity Ratio 14Å/10Å	Feldspar in Fine Sand
	Loc. 18	Ca. 30 km northwest of Nakhon Sawan								
		hard laterite								
5										
	18–1	white (5Y8/2)(dry) heavy clay, common red concretionary mottles and reddish yellow, cloudy mottles		4.5	56.1	0.23	75	1.02	0.25	+
50										
	–2	white (2.5Y8/2)(dry) heavy clay, few red concretionary mottles and reddish yellow cloudy mottles	III	4.5	54.6	0.18	70	1.00	0.50	+
90										
	–3	as same as above, but mottles decrease		4.6	40.4	0.17	65	0.88	0.40	++
130										
	–4	as same as above, but mottles are almost absent		5.4	19.3	0.38	60	0.71	0.33	++
	Loc. 20	Right bank of the Ping, Klong Klung								
	20–1	pinkish gray (5YR6/2)(dry) heavy clay, few yellowish red cloudy mottles	I	5.4	54.4	0.66	50	0.60	0.67	
120										
	–2	reddish gray (5YR7/2)(dry) light clay, many reddish yellow cloudy mottles	II	5.3	40.7	0.37	70	0.79	0.50	++
220										
	–3	pinkish gray (5YR6/2) and reddish yellow (7.5YR7/6) indurated heavy clay	III	4.9	49.7	0.12	80	0.90	0.33	++
	Loc. 21	Ca. 2 km northwest of Klong Klung								
	21–2	pinkish gray (7.5YR7/2)(dry) heavy clay, common dark brown cloudy mottles, few manganese spots	I	5.3	45.0	0.48	60	0.76	1.00	++
15										
	–2	reddish gray (5YR5/2)(dry) light clay, many dark reddish brown cloudy mottles	I	4.6	42.5	0.46	60	0.76	1.00	++

	-3	pinkish gray (5YR6/2)(dry) light clay, common very dusky red spots	I	4.9	40.0	0.44	60	0.76	1.00	++
95										
	-4	grayish brown (10YR5/2)(dry) sandy clay, hardly indurated with gravels, common dark brown cloudy mottles	II	5.8	34.1	0.22	70	1.02	1.00	+++
115										
	-5	liglt gray (10YR7/2)(dry) heavy clay, common reddish yellow cloudy and fibrous mottles	II	6.2	45.3	0.55	65	0.88	0.75	++
135										
	-6	grayish brown (10YR5/2)(dry) heavy clay, few reddish yellow cloudy mottles, few manganese spots	II	6.9	53.6	0.39	75	0.90	1.50	+++
185										
		hard laterite	III							
190										
	-7	reddish gray (2.5YR7/2)(dry) heavy clay, common reddish yellow and yellowish red spots and filmy mottles	III	6.7	52.1	0.21	70	0.94	5.00	++
	-8	brown (7.5YR5/2)(dry) heavy clay, common dark brown cloudy mottles	III	9.7	55.3	0.20	75	0.96	1.50	++
	Loc. 23	Ca. 1 km north of Pran Krathai								
		white (10YR8/2)(dry) clay loam, many yellow fibrous mottles								
10										
	23-2	white (10YR8/2)(dry) clay loam, profuse iron nodules	III?	6.3	24.6	1.11	45	0.91	0.57	-
20										
	-3	white (10YR8/2)(dry) light clay, few yellowish brown cloudy mottles, few iron nodules, common lime nodules	III?	5.6	31.4	1.31	50	1.05	1.00	-